Study Committee A2

Power Transformers and Reactors

10100_2022

Condition Assessment of HVDC converter transformers at limited time of outage applied to the Fenno–Skan 1 transmission system

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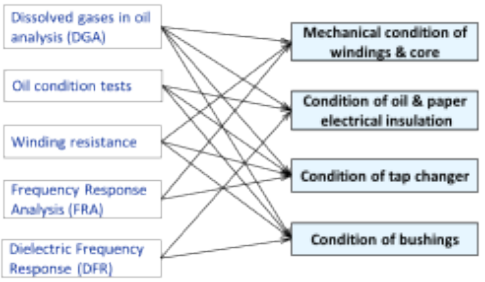
Motivation

- After more than 30 years in operation it has become necessary to evaluate operational risks of the converter transformers and make a strategic decision on the possibility of extending their service lifetime.
- In the present study we describe key points to consider when performing condition assessment of HVDC converter transformers.

Method/Approach

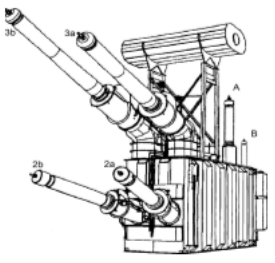
- Modern diagnostic tools addressing critical failure modes;
- Evaluate parameters using specific thresholds if applicable;
- Take into account limitations on site.



Objects of investigation

- Dannebo Converter Station is served by 3 single-phase units.

Manufacturer	Hitachi Energy (former ABB)
Year	1988
Cooling type	OFAF
Number of phases	1
Rated Frequency	50 Hz



Terminals	Rated voltage [kV]	Rated Power [MVA]	Rated Current [A]
A B (AC winding)	$\frac{405/\sqrt{3}}{+\frac{+18}{-7}} \times 1.25\%$	194,6	680 – 832 – 913
2a 2b (Y-connected Valve winding)	161,4/√3	97,3	1045
3a 3b (Δ- connected Valve winding)	161,4	97,3	1045/√3

Experimental setup & test results

Method indicated an abnormality	Detected abnormality	Recommendations for remedial actions to maintain short-term reliability
Winding resistance	Measured values are acceptable. Suspected early evidence of the formation of an oxidation film on the contact surfaces	The formed films are generally removed by switching the on-load tap changer (OLTC) through its full cycle thanks to the wiping action of the moving contacts
Oil analysis for the oil from the transformer main tank	The results do not indicate any abnormal condition. Meanwhile metal passivator content has dropped below the level that is normally considered acceptable	As a short-term solution, addition of more passivator is suitable. For continued long-term operation oil reclaiming or oil change may be more suitable alternatives
DGA and oil analysis for the oil from the OLTC	DGA results indicate an incipient hot run in the OLTC. Oil analysis shows that the breakdown voltage is low and does not meet the requirement of IEC 60422	The oil in the diverter switch tank should be changed. In connection with this, a service on the OLTC should also be performed (as well as checking the contacts). An alternative solution is to upgrade the diverter switches to a vacuum type
Visual inspection	Oil leakages and damaged paintwork detected	Eliminate the oil leakages, recover the paintwork

Discussion

- As these converter transformers have been in service for more than 30 years, it was recommended to perform estimation of the paper insulation aging rate.
- If paper aging status is suitable, then to ensure transformers reliability for the upcoming 20 years, the manufacturer of the transformers has recommended:
  - A replacement program for the transformer bushings. Dry insulated bushings are recommended for replacement;
  - Upgrade OLTC diverter switches to a vacuum type;
  - Replacement of gaskets;
  - Replacement of transformer accessories which exceed expected lifetime (such as control cabinets, cabling, temperature indicators, pressure relay, Buchholz relay and others).

Conclusion

- Valuable information about condition status of the transformers has been obtained during challenging limited conditions thanks to close cooperation between the manufacturer of the transformers and the grid owner as well as to the set of modern diagnostic tools applied.
- The grid owner has received recommendations on how to improve short-term reliability of the transformers as well as how to keep them functioning properly. Suggestions were also given regarding the possibility to extend service lifetime.

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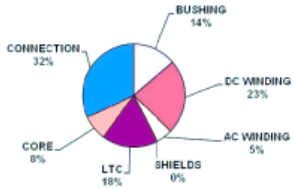
Choosing diagnostic methods

- HVDC transformers are specific in design as well as the operational stresses they face during operating life. This leads to differences in failure distribution by component and influences the choice of methods utilized for condition assessment
- HVDC-specific limitation factors on site:
  - DC terminals are located inside the valve hall, while AC terminals are outside. It was not possible to pull the test leads through the valve hall wall, therefore the measurements which require connection to AC and DC terminals at the same time were not applicable.
  - it was a problem to remove external connections from DC terminals which influenced the choice of methods utilized for condition assessment.
  - time for electric measurements was restricted to maximum one day per transformer



Failures of HVDC transformers by component 2003 -2012

[CIGRE Brochure 617, 2015 "HVDC LCC converter transformers. Converter transformer failure survey results from 2003 to 2012"]

Diagnostic Methods

Type		Method	Object
Chemical		DGA (Dissolved Gas Analysis)	Electrical and/or thermal fault diagnosis
		Oil condition tests	Determination of oil condition
Electrical	Basic	Winding resistance	Detection of bad contacts, winding short circuits and interruptions
		Excitation current	Problems associated with the core; indication of winding short circuits and interruptions
		Turns ratio	Detection of winding short circuits and interruptions
		Insulation resistance	Estimation of insulation condition, indication on moisture ingress, contamination, aging, etc.
		Capacitance and dissipation factor (tan δ) or PF	
		Short-Circuit Impedance	Detection of winding short circuits and active part deformations
	Advanced	Sweep Frequency Response Analysis (SFRA)	Detection of winding short circuits and active part deformations – provides more accurate information than basic measurements
		Dielectric Frequency Response (DFR), also known as Frequency Domain Spectroscopy (FDS)	Estimation of insulation condition – provides more accurate information than basic measurements
		Partial discharges (PD)	Detection of weak spots inside the insulation system
Acoustic		Partial discharges (PD)	Detection of weak spots inside the insulation system
		Acoustic sound level	Acoustic noise level of a transformer
Others		Theoretical paper ageing calculation	Determination of paper aging rate
		Thermography	Detection of heat sources and hot spots
		Vibration signal analysis	Mechanical properties of active part, accessories
And other methods…			

- The more diagnostic methods that are included in the transformer condition assessment, the more accurate result is expected. On the other hand, every additional method applied increase needed outage time, sometimes demands additional measuring equipment, special experts, preparational work, etc. which may dramatically increase complicity of the project and its costs.

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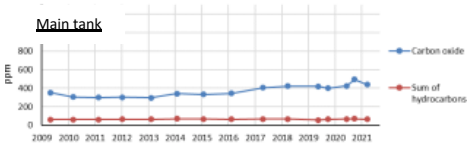
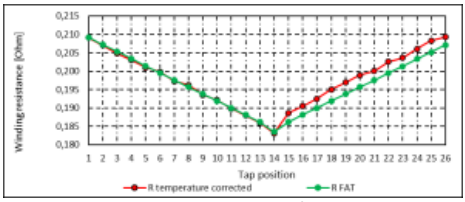
DGA



OLTC

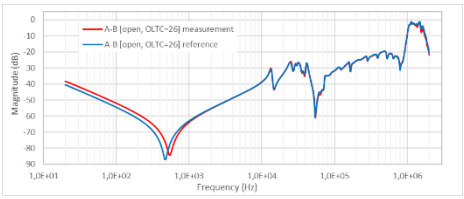
Gas	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	CO_2
[µl/l]	18900	3800	1100	8780	5600	672	7560

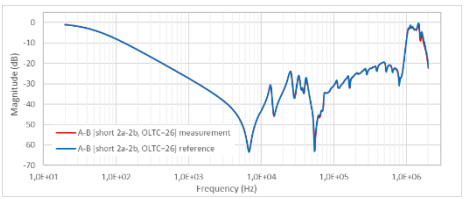
Winding resistance measurement

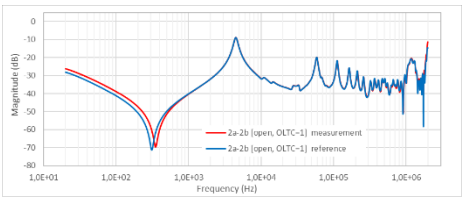


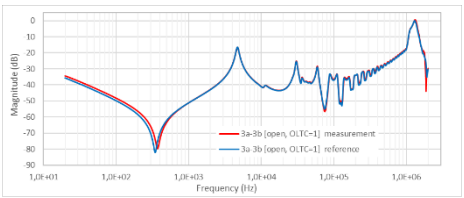
Winding resistance measurement results of the Line winding

SFRA measurement

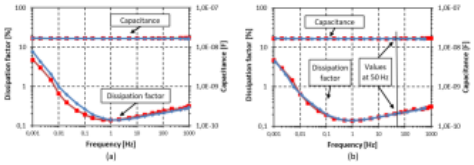




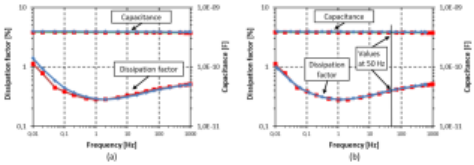




DFR measurement



DFR response of Line winding insulation (red) compared with the reference response from a sister unit (blue): (a) before temperature compensation; (b) after temperature compensation – normalized to 20 °



DFR response of a bushing of Δ- connected Valve winding (red) compared with the reference response from a sister unit (blue): (a) before temperature compensation; (b) after temperature compensation – normalized to 20 °C

Conclusion

- Since Dannebo Converter Station is served by 3 single-phase units of identical design, measurement results obtained on one unit can be used as a baseline for another one. This is very helpful especially for DFR and SFRA results interpretation.
- Valuable information about condition status of the transformers has been obtained during challenging limited conditions thanks to close cooperation between the manufacturer of the transformers and the grid owner as well as to the set of modern diagnostic tools applied.
- The grid owner has received recommendations on how to improve short-term reliability of the transformers as well as how to keep them functioning properly. Suggestions were also given regarding the possibility to extend service lifetime.